CP. 404

CP 4

Breeding Groundnut Cultivars Resistant to Rust (*Puccinia arachidis* Speg.)

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Abstract

An array of rust-resistant groundnut breeding lines has been generated at ICRISAT Center, from selection within segregating natural hybrids received from the United States, and from many crosses made between rust-resistant germplasm accessions and agronomically superior but rust-susceptible parents. Advanced breeding lines, with good yield potential, have been entered in national trials in India. The resistant lines are suitable for oil expressing but pod and seed characters need to be improved for their use as confectionery products. Some of the breeding lines also have resistance to other biotic and abiotic stresses. Preliminary studies on the genetics of rust resistance indicate that two or three duplicate recessive genes are involved in conferring resistance. Quantitative data revealed significant additive, additive × additive, and additive × dominant gene effects involved in resistance.

Résumé

Sélection de cultivars d'arachide résistants à la rouille (Puccinia arachidis Speg.) : *Au Centre ICRISAT, en Inde, on a produit une diversité de lignées de sélection résistantes à la rouille à partir d'hybrides naturels en ségrégation provenant des Etats-Unis et d'un grand nombre de croisements effectués entre des accessions résistantes et des géniteurs sensibles mais à bons caractères agronomiques. Les lignées en sélection avancée ayant un haut potentiel de rendement, ont été inscrites aux essais nationaux en Inde. Les lignées résistantes possèdent de bons caractères pour l'extraction de l'huile, il faut cependant améliorer les caractères de la gousse et des graines avant de les destiner à la confiserie. Certaines lignées de sélection présentent également une résistance à d'autres stress biotiques et abiotiques. Les études préliminaires sur la génétique de la résistance mettent en évidence deux à trois gènes récessifs doubles qui transmettent cette résistance. Les données quantitatives ont révélé des effets additifs significatifs : additif × additif et additif × gène dominant.*

Groundnut rust, caused by the fungus *Puccinia arachidis* Speg., is a serious foliar disease in many groundnut-growing countries (Bromfield 1974, Hammons 1977, Subrahmanyam et al. 1980) causing severe yield losses (Burger 1921, Muller 1950). At ICRISAT Center, rust in conjunction with late leaf spot can cause yield losses of over 70% in susceptible cultivars, while rust disease on its own is capable of causing up to 50% yield loss (Subrahmanyam et al. 1980). In addition to the direct yield losses, rust disease can lower seed quality by reducing seed size (Arthur 1929, South 1912) and oil content (Castellani 1959).

Prior to the establishment of the Groundnut Improvement Program at ICRISAT, a few rust-resistant sources had been reported (Mazzani and Hinojosa 1961, Bromfield and Cevario 1970, Bailey et al. 1973). Extensive field screening of over 9000 accessions from the world collection of groundnut germplasm at ICRISAT Center, where severe rust disease epidemics occur in the rainy season, has resulted in the identification of new sources of resistance and resistant genotypes are currently available (Subrahmanyam et al. 1980; Subrahmanyam and McDonald 1983). In addition, 61 wild *Arachis* species accessions have been screened for rust resistance

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and most of them were found to be immune, 6 being highly resistant and 2 susceptible to the pathogen (Subrahmanyam et al 1983)

It was considered that the development of disease-resistant cultivars would be the most effective and practical solution for resource-limited peasant farmers in the semi-arid tropics This paper describes the breeding efforts that are under way in the development of rust-resistant cultivars with special emphasis on agronomic evaluation of resistant sources, breeding methodology, selection procedures, yield levels, and the stability of yield, and resistance of the advanced resistant selections In addition genetic studies of rust resistance have been initiated

Evaluation of Rust-resistant Germplasm

As knowledge of the variability available within a given gene pool is a prerequisite for its effective

Table 1. Range of variability within the rust-resistant groundnut germplasm.

Character	Range
Plant height (cm)	49 0-20 4
Plant width (cm)	67 0-34 8
No of primary branches (N+1s)	9 2- 3 1
No of secondary branches (N+2s)	14 5-0
No of nodes/main stem	23 9-14 9
No of nodes/N+1 branch	22 5-12 9
Pegs/node	2 1- 1 2
No of pegs plant	84 8-12 1
Internode length (cm)/main stem	2 7- 0 7
Internode length (cm)/N+1 branch	5 8- 1 1
Leaf area (cm²)	44 6-21 7
Fresh haulm wt plant (g)	89 3 30 8
Pod weight/plant (g)	29 5-13 7
No of mature pods plant	16 3- 7 2
No of immature pods/plant	5 3- 0 3
No of mature seeds/plant	39 0-11 4
No of immature seeds/plant	10 8- 0 9
Seed weight/plant (g)	17 8- 9 5
Days to 75% flowering	
Rainy season	25-33
Postrainy season	30-42
Pod yields (kg ha ⁻¹)	
Rainy season	2580 840
Postrainy season	8139-3694
100-Seed weight (g)	
Rainy season	47 6-22 2
Postrainy season	88 1-41 0
Shelling percentage (Rainy season)	72-45

utilization, the 41 germplasm accessions identified as rust-resistant (V R Rao, these proceedings) were evaluated in replicated trials for various morphological and agronomic characters including yield and yield attributes Considerable variation within the rust-resistant germplasm was observed for most of the characters studied (Table 1) Yield trials were conducted at ICRISAT Center in the rainy season when rust disease is severe, and in the postrainy season when it is not Trials were also conducted at Bhavanisagar where rust is not a serious problem in the rainy season These trials showed that some of the rust-resistant lines had good yield potential (Table 2) However, they also had some undesirable pod and seed characteristics, including hard shells (which were difficult to open), deep constrictions, and dark purple or variegated seeds

The choice of the parents in a hybridization program is very important for proper resource utilization, and in an international program where the main goal is to generate broad-based breeding populations it is essential to use diverse parents in the crossing program Mahalanobis' D^2 analysis and canonical analysis were employed to assess the magnitude of divergence in the rust-resistant germplasm These analyses, based on 14 different agronomic and morphological characters, resulted in the identification of 5 clusters based on rust resistance The first

Table 2. Mean pod yields (kg ha ⁻¹) of some germplasm lines resistant to foliar diseases.

	ICRISAT Center		Bhavanisagar
Pedigree	Rainy season, 1983	Postrainy season, 1983 84	Postrainy season, 1983 84
PI 407454	2146	8139	2100
Krap St 16	2583	6514	2800
PI 393531	2115	7194	2233
PI 390593	2229	7561	1667
PI 393646	1958	7208	1908
PI 341879	2031	6369	2300
PI 393641	2094	6271	1983
PI 270806	1938	6174	2150
PI 350680	2323	6000	1916
PI 381622	1917	5694	2167
Robut 33-1 (Sus cultivar)	1094	4653	1850
J 11 (Sus cultivar)	990	4639	633
SE	±178	±44	±484
CV %	15	7	25

Table 3 Intra- and intercluster average D^2 values of rust-resistant lines based on Mahalanobis' D^2 analysis and canonical analysis.

	I (33)[1]	II (2)	III (4)	IV (1)	V (1)
I	7 4	12 9	15 5	15 1	13 8
II		5 2	12 8	10 3	10 2
III			9 1	15 3	10 3
IV				0 0	17 1
V					0 0

1 Figures in parentheses refer to number of genotypes representing each cluster

cluster consisted of 33 genotypes, the second of 2 genotypes, the third of 4 genotypes, and the fourth and fifth clusters of 1 genotype each (Table 3) Although the first cluster consisted of 33 genotypes, the intra-cluster average D^2 value (7 9) was less than that of the third cluster (9 1) consisting of only 4 genotypes This indicates that cluster III is more variable than cluster I The inter- and intracluster D^2 values are taken into consideration when selecting parents

Utilization

Methodology (Fig. 1)

Over 700 single, double, and triple crosses were made using the rust-resistant germplasm lines and high-yielding but susceptible released cultivars from various countries A wide array of rust-resistant breeding populations were generated and supplied to cooperators At ICRISAT Center, the F_1s were generally grown at wide spacing in the postrainy season to get maximum seed return From the F_2 to F_5 generations, the material was grown in the disease nursery using an infector-row method (Subrahmanyam and McDonald, these proceedings) The truncation method of selection for resistance was adopted and plants that received scores of less than 5 on the 9-point disease scale were classified as resistant Plants with scores of 5 to 6 were classed as moderately resistant, and those with scores greater than 6 as susceptible The three categories were further subdivided into high-yielding, moderately-yielding, and low-yielding bulks on the basis of an eyeball index Only the susceptible and low-yielding bulks were rejected in the early generations In the F_5 generation, sister lines were bulked on the basis of

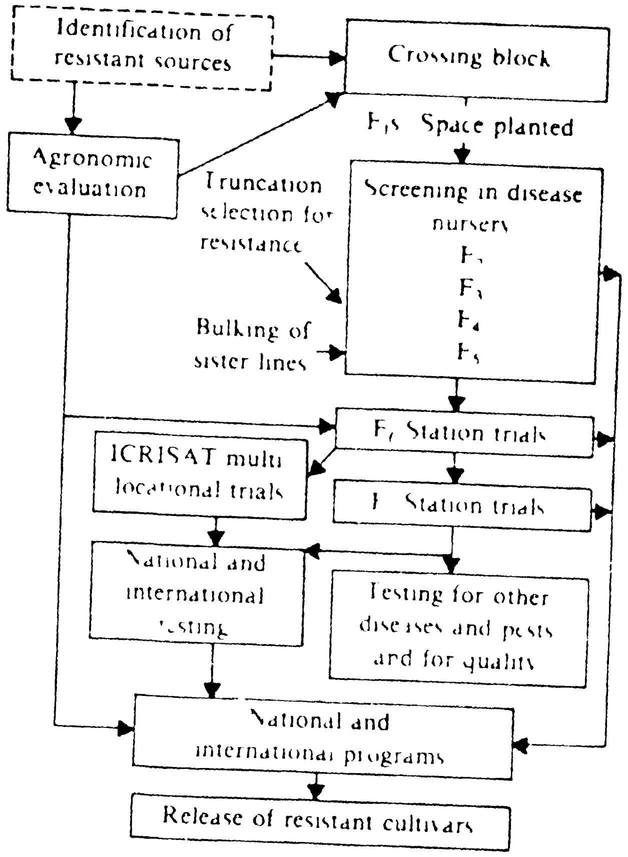

Figure 1. Basic scheme for development of rust-resistant groundnut cultivars.

their levels of resistance, visual yield, pod, and seed characteristics The F_6 bulks were evaluated at ICRISAT Center under both high-input (60 kg P_2O_5 ha⁻¹, supplemental irrigation and insecticide sprays when required) and low-input (20 kg P_2O_5 ha⁻¹, rainfed and no insecticide sprays) conditions during the rainy season In the postrainy season the trials were conducted only under high-input conditions

The stability of yield performance and rust-resistance of the promising lines identified at ICRISAT Center was checked by conducting multilocational tests within India at Bhavanisagar (red gravelly Alfisol, 11°N latitude), Dharwad (Vertisol, 15°N latitude), Anantapur (shallow Alfisols, drought-prone area, 14°N latitude) and Hisar (sandy loam, 29°N latitude) To identify lines with broad adaptability and lines suited to specific agroecological zones, advanced rust-resistant breeding lines are also being extensively tested in India through the All India Coordinated Research Project on Oilseeds (AICORPO)

Most of the rust-resistant advanced breeding lines have also been evaluated for their reaction to other major diseases and pests, and for seed quality

Progress

Infra- and intrasubspecific hybridization

From crosses involving predominantly valencia-type rust-resistant germplasm and some high-yielding rust-susceptible virginia and spanish cultivars, a large number of high-yielding, rust-resistant lines with commercially acceptable pod and seed characteristics have been bred Several of these advanced breeding lines outyielded the popular Indian cultivars Robut 33-1 and JL 24 under both high- and low-input conditions (Table 4) In the high input trial in the rainy season some rust-resistant lines such as ICG(FDRS) 29 and ICG(FDRS) 30 produced over 4000 kg ha^{-1} compared to 2890 kg ha^{-1} from the best rust-susceptible check cultivar JL 24 These lines were also superior to JL 24 in the low-input trial (Table 5) Even in the postrainy season when rust disease is negligible, some of the resistant breeding lines yield well (Table 6) A few advanced rust-resistant lines such as ICG(FDRS) 11, 21, 10, 22 and 27 showed consistently higher yields across years and seasons at ICRISAT Center than the rust-susceptible cultivar Robut 33-1 (Table 7).

Table 4. Summary of the rust-resistant advanced groundnut lines yield trials, ICRISAT Center, rainy season 1983.

Trial	No of resistant selections tested	Number of lines significantly outyielding Robut 33-1		JL 24	
		HI[1]	LI[2]	HI	LI
$F_{6/7}$	21	9	3	16	20
F_8	35	25	3	14	30
F_9	60	52	13	56	57
F_{10}	37	10	6	8	31
F_{10} (Rainfed selections)	15	0	2	4	14
F_{11}	22	7	1	13	13
F_{11} (Rainfed selections)	19	3	6	3	17
Multilocational trial	46	14	1	10	39
FDRVT	17	3	3	9	6
Total	272	123	38	133	227

1 HI = High input (60 kg P_2O_5 ha^{-1} with irrigation and insecticide sprays when necessary) trial
2 LI = Low input (20 kg P_2O_5 ha^{-1} rainfed and no insecticide sprays) trial

Table 5. Pod yields of foliar-diseases resistant advanced lines, ICRISAT Center, rainy season 1983.

Identity	Pod yield (kg ha^{-1}) HI[1]	LI[2]	Rust Score[3]
ICG(FDRS) 19	3710	2610	3 3
ICG(FDRS) 20	3800	2540	3 2
ICG(FDRS) 23	3990	2500	3 8
ICG(FDRS) 29	4290	2220	3 3
ICG(FDRS) 30	4260	2050	3 0
Robut 33-1 (Sus check)	2600	2150	7 8
JL 24 (Sus check)	2890	1340	8 7
SE	±203	±148	±0 4
CV (%)	12	13	17 6

1 HI - High input trial (60 kg P_2O_5 ha^{-1} with irrigation and insecticide sprays when necessary)
2 LI = Low input trial (20 kg P_2O_5 ha rainfed and no insecticide sprays)
3 Scored on a 9 point scale 1 = no disease and 9 = 50 to 100% of foliage destroyed

Table 6. Pod yields of foliar-diseases resistant lines, ICRISAT Center, postrainy season 1983/84.

Trial	Identity	Yield (kg ha^{-1})	Rust score[1]
F_{11}	(GAUG-1 × EC 76446(292)-F11B	8320	3 2
	(JH 60 × PI 259747)-F11B	7890	2 8
	(Ah 8254 × NC Ac 17090)-F11B	7860	3 0
	Robut 33-1	6630	8 7
	SEM	±322	±0 3
	CV (%)	8 4	16 5
F_9	(NC Fla 14 × 17090)-F9B	8150	2 5
	Robut 33-1	6740	6 7
	SEM	±246	±0 4
	CV (%)	6 6	20 5
MLT[2]	(NC Ac 2190 × 17090)-F10B	8330	4 3
	(SM 1 × EC 76446(292)-F11B	8170	4 5
	Robut 33-1	6260	7 0
	SEM	±229	±0 4
	CV (%)	6 3	17 6

1 Scored from 1983 rainy season trials on a 9 point scale, 1 = no disease and 9 = 50 to 100% foliage destroyed
2 MLT = Multilocational Trial

Table 7. Pod yields (kg ha^{-1}) of some rust-resistant selections over seasons and years at ICRISAT Center

Identity	1982 R	1983 R HI[1]	1983 R LI[2]	1983 84 PR	1984 R HI	1984 R LI
ICG(FDRS) 11	2680 (1350)[3]	3010 (2730)	2560 (2250)	3640 (3250)	5850 (4690)	1080 (610)
ICG(FDRS) 21	2260 (1510)	3530 (2600)	2310 (2150)	6720 (6260)	5990 (4690)	920 (610)
ICG(FDRS) 10	3020 (1350)	3540 (2730)	3250 (2250)	3620 (3250)	5620 (4690)	1030 (610)
ICG(FDRS) 22	2400 (1350)	3040 (2600)	2290 (2150)	7100 (6260)	5880 (4690)	990 (610)
ICG(FDRS) 27	2320 (1510)	3760 (2410)	1670 (1010)	6130 (6125)	5700 (4690)	970 (610)

1 HI High input trial (60 kg P_2O_5 ha^{-1} with irrigation and insecticide sprays when necessary)
2 LI Low input trial (20 kg P_2O_5 ha^{-1} rainfed and no insecticide sprays)
3 Figures in parentheses refer to yields of the susceptible cv Robut 33 1
R = Rainy season PR = Postrainy season

Exploitation of natural hybrids

Although natural outcrossing poses problems in maintaining the purity of cultivars, it can also serve as a source of additional genetic variation that can be profitably exploited, especially in a crop such as groundnut where artificial crossing is tedious Several workers (Hammons 1964, Gibbons 1971, Hildebrand and Smartt, 1980) have indicated the usefulness of natural hybrids in groundnut improvement Recently at ICRISAT, Nigam et al (1983) demonstrated the usefulness of natural hybrids in developing high-yielding lines

In 1973 the United States Department of Agriculture and the Virginia Agricultural Experiment Station released 14 rust-resistant selections made from the progeny of a single natural hybrid between PI 298115 (Israel 136) and an unknown pollen donor (Bailey et al 1973) These fourteen F_3-derived rust-resistant lines (referred to as FESR lines) were received by ICRISAT in 1977 and their progeny segregated for rust reaction and for some morphological characters All the lines were progeny-rowed in the next generation when they were again segregated for rust reaction Several hundred selections were purified and advanced to the F_8 generation by which stage they were fairly uniform and more or less true breeding Some of these F_8 rust-resistant lines were also found to be highly resistant to late leaf spot (Nigam et al 1980, Subrahmanyam et al 1980) While these FESR selections in general wer low yielding compared to popular, high-yieldin susceptible, Indian cultivars such as Robut 33-1 they served as excellent parental sources of multip resistance to rust and late leaf spot One of th advanced FESR selections, ICG(FDRS) 14, th showed consistently superior yield performan over the check cultivars at ICRISAT Center is cu rently being tested in several Indian locations t AICORPO

Mutation breeding

The direct use of mutations is a valuable suppleme tary approach to plant breeding, particularly wh used to improve a few easily identifiable characte in an otherwise well-adapted variety

The rust-resistant genotype NC Ac 17090 is wid adapted and has good yield potential However possesses the undesirable pod characteristics thick shells, and long, reticulated pod In an atten to eliminate these undesired characteristics NC 17090 was treated with gamma rays (25 kr, 35 k ethyl methane sulphonate (0 1% and 0 2%) a nitrosomethyl urea (0 001% and 0 003%) The p genies are currently in the M_3 generation and so useful pod mutants have been identified and being further evaluated

Stability of yield [illegible] of rust-resistant lines

To test the stability of [illegible], 40 rust-resistant advanced [illegible] and 6 breeding lines with combined [illegible] and late leaf spot, were evaluated [illegible] the rust-resistant genotype NC Ac 17090 [illegible]-susceptible cultivars, JL 24 and Robut 33-1 [illegible] environments in India. Sixteen resistant [illegible] higher mean yields than the highest-yielding [illegible] cultivar Robut 33-1, and 3 lines were [illegible] resistant parent NC Ac 17090. A stability [illegible] was carried out according to the method [illegible] and Russel (1966). Two breeding lines [illegible] combined resistance to rust and late leaf spot [illegible] PI 259747) F10B and (GAUG-1 × PI 259747 [illegible]) showed regression coefficients close to [illegible] nonsignificant deviations (S values [illegible]) [illegible] they are more stable than the adapted [illegible] cultivars (Table 8). Similarly several rust-resistant lines showed better stability across the five environments than the susceptible cultivars.

Yield performance of resistant lines in national trials

In India, the rust-resistant breeding lines developed at ICRISAT are being tested extensively in the Foliar Diseases Resistance Varietal Trial (FDRVT) conducted by AICORPO. To date, 38 rust-resistant lines have been entered in these trials. The yield advantage of rust-resistant lines varied from location to location, and the best line, ICG(FDRS) 10, showed a 17% yield advantage over the highest yielding rust-susceptible cultivar JL 24 on the basis of overall mean yield during the 1983 rainy season (Table 9). The AICORPO requires four stages of testing before any cultivar is released for general cultivation. Currently ICG(FDRS) 4 is in the third stage of testing in the Peninsular Zone of India. Lines ICG(FDRS) 1, ICG(FDRS) 10 and ICG(FDRS) 23 are in the second stage of evaluation in all six testing zones of India. Another eight lines are in the first stage of testing.

In the Philippines the rust-resistant lines showed from 4 to 36% yield advantage over the local rust-susceptible check cultivar Biyaya in a trial conducted by the San Miguel Corporation. The resistant lines also had larger seed and a higher shelling percentage than Biyaya.

Table 8. Stability parameters for yield (kg ha^{-1}) of the rust and late leaf spot-resistant advanced lines.

Identity	Mean over 5 environments	Regression coefficient	Significance
(JH 335 × NC Ac 17090)F9B	2986	1.51	35 179
(JH 171 × NC Ac 17090)F6B	2980	1.42	565 929**
(Ah 6279 × PI 259747)F9B	2848	1.58	240 261*
(NC Ac 2190 × NC Ac 17090)F8B (S1)	2628	1.07	270 742*
(NC Ac 2190 × NC Ac 17090)F8B (S2)	2620	1.25	176 366
(Var. 2-5 × PI 259747)F10B	2580	0.93	142 899
(GAUG 1 × PI 259747)F9B [illegible]	2512	0.90	118 662
NC Ac 17090 (Resistant check)	2388	1.54	588 078**
Robut 33-1 (Susceptible check)	2484	0.64	340 360**
JL 24 (Susceptible check)	2180	1.23	639 484**

Table 9. Pod yields (kg ha^{-1}) of some rust-resistant lines in the foliar diseases resistance varietal trial, India, rainy season 1983.

	Center						
Identity	Anantapur	Dharwad	Kadiri	ICRISAT	Tirupati	Vriddha-chalam	Mean
ICG(FDRS) 10	[illegible]	4240	2040	3250	1800	1770	2683
ICG(FDRS) 2	[illegible]	3090	[illegible]	1860	2110	2640	2355
ICG(FDRS) 4	[illegible]	2720	[illegible]	2620	1960	2480	2192
ICG(CG;FDRS) 17	[illegible]	2470	2140	3540	1850	1830	2303
JL 24 (Sus. cultivar)	[illegible]	3080	[illegible]	1540	2040	2140	2285
SE	[illegible]	±394	±123	±189	±83	±46	
Trial mean	[illegible]	2970	[illegible]	2160	1730	1850	
CV (%)	[illegible]	20	10	17	[illegible]	6	

Reaction of rust-resistant lines to other diseases and pests

Several rust-resistant breeding lines were found to have resistance to late leaf spot (incited by *Phaeoisariopsis personata* (Berk. and Curt.) v. Arx). During the 1983 rainy season when the late leaf spot disease was severe, 30 lines showed late leaf spot severity scores of less than 5 on the 9-point disease scale at ICRISAT Center.

Genotype ICG(FDRS) 4 showed tolerance to peanut mottle virus; less than 10% yield loss compared to about 40% yield loss in TMV 2, a susceptible check cultivar, when artificially inoculated. Se[illegible] one of the FESR lines supported production of very low levels of aflatoxin although it was re[illegible] colonized by *Aspergillus flavus*. Three FESR [illegible] showed tolerance to termites (Table 10). Abou[illegible] rust-resistant breeding lines were evaluated for [illegible] resistances to drought, leafhoppers, leafminer, [illegible] bud-necrosis disease. Six lines showed toleranc[illegible] terminal drought stress in two years of testing (T[illegible] 10). Several lines showed good levels of resistanc[illegible] leafhoppers, bud-necrosis disease, and leafmi[illegible] Screening is continuing to confirm these resistan[illegible]

Table 10. Some rust-resistant lines with other useful attributes.

Identity	Remarks
ICG(FDRS) 4	Tolerant to peanut mottle virus
FESR 12-P6-B_1-B_1-B_1	Low aflatoxin-producing line
[(G 37 × EC 76446(292)]F_7B	Drought tolerant
(JH 60 × PI 259747)F_8B	Drought tolerant
(M 145 × PI 259747)F_{11}B	Drought tolerant
(JH 335 × NC Ac 17090)F_9B	Drought tolerant
(NC Ac 400 × NC Ac 17090)F_{10}B	Drought tolerant
(G 37 × NC Ac 17090)F_9B	Drought tolerant
(Ah 8254 × PI 259747)F-11 B	Resistant to jassids
(Ah 6279 × PI 259747)F_{11}B(S1)	Resistant to jassids
(M 13 × DHT 200)F_8B	Resistant to jassids
(Ah 6279 × PI 259747)F_{11}B(S2)	Resistant to jassids
(GAUG 1 × NC Ac 17090)F_8B	Resistant to jassids
MGS 9 × EC 76446(292)F_8B	Resistant to jassids
MGS 8 × NC Ac 17090 F_8B	Resistant to jassids
Ah 65 × NC Ac 17090 F_8B	Resistant to jassids
FESR 1-P3-B_1-B_1-B_1	Tolerant to termites
FESR 1-P9-B_1-B_2-B_1	Tolerant to termites
FESR 2-P3-B_1-B_1-B_1	Tolerant to termites

Quality aspects of rust-resistant lines

The quality attributes of advanced breeding lines [illegible] routinely monitored to ensure that they are not i[illegible] rior to existing commercial cultivars. The m[illegible] advanced rust-resistant lines from trials at three [illegible] ferent locations in India were analysed for oil a[illegible] protein contents of seeds. The oil contents of seed[illegible] rust-resistant lines were slightly higher than those [illegible] rust-susceptible check cultivars and the protein c[illegible] tents were almost identical (Table 11).

Genetics of rust resistance

Observations in the USA by Bromfield and Bail[illegible] (1972) on F_2 plants of a natural cross between [illegible] rust-resistant female parent, PI 298115 and a[illegible] unknown pollen donor indicated digenic inheri[illegible] ance, with resistance being recessive. Further studie[illegible] on advanced derivatives (F_3 derived FESR familie[illegible]) of the same cross at ICRISAT Center confirmed th[illegible] recessive nature of the resistance, but continue[illegible] segregation within the highly-resistant progenie[illegible] suggested that more than two genes were involve[illegible] (Nigam et al 1980). Later studies at ICRISAT on F[illegible] plants from crosses involving three susceptible an[illegible] three resistant parents suggested digenic inheritanc[illegible] (15 susceptible : 1 resistant) in some crosses an[illegible] trigenic inheritance (63 susceptible : 1 resistant) in others (Kishore, 1981). Based on studies of F_2 and F_3 generations from crosses between three resistant and one susceptible cultivar Knauft and Norden (1983) reported the involvement of two recessive duplicate genes in the inheritance of rust resistance. Recent studies at ICRISAT (Nigam, personal communication) have supported this interpretation in some crosses.

Genetic analysis of parents, F_1, F_2, BC_1 and BC_2

Table 11. Oil and protein content of the groundnut entries in the foliar-diseases resistant varietal trial, rainy season 1983.

	Location							
	ICRISAT		Aliyarnagar		Tirupati		Mean over locations	
Genotype	Oil %	Protein %	Oil %	Protein %	Oil %	Protein %	Oil %	Protein %
ICG(FDRS) 1	45.1	23.3	50.6	24.4	46.7	29.0	47.5	25.6
ICG(FDRS) 2	41.1	23.5	46.3	24.5	43.0	29.4	43.5	25.8
ICG(FDRS) 4	45.3	24.9	48.7	25.2	46.6	29.1	46.9	26.4
ICG(FDRS) 5	41.8	23.7	46.1	28.1	46.1	25.6	44.7	25.8
ICG(FDRS) 6	46.5	23.4	47.8	25.3	44.3	30.4	46.2	26.4
ICG(FDRS) 7	45.5	24.3	46.8	28.2	43.2	31.1	45.2	27.9
ICG(FDRS) 8	48.7	22.7	48.2	22.9	46.2	29.0	47.7	24.9
ICG(FDRS) 9	45.9	25.4	49.8	25.0	45.1	33.0	46.9	27.8
ICG(FDRS) 10	46.7	25.1	49.6	26.1	46.8	28.5	47.7	26.6
ICG(FDRS) 11	42.0	22.9	47.1	25.3	43.1	29.9	44.1	26.0
ICG(FDRS) 12	42.9	24.2	47.2	25.1	43.1	31.1	44.4	26.8
ICG(FDRS) 13	40.5	23.3	43.1	26.8	41.8	30.1	41.8	26.7
ICG(FDRS) 14	51.2	24.0	49.7	29.2	48.4	32.4	49.8	28.5
ICG(FDRS) 15	41.7	23.9	48.8	23.4	46.0	29.6	45.5	25.6
ICG(FDRS) 16	45.1	23.4	47.4	23.4	43.6	30.9	45.4	25.9
ICG(FDRS) 17	44.7	26.4	44.7	28.4	46.4	31.9	45.3	28.9
ICG(FDRS) 18	47.6	26.9	47.7	27.2	46.6	31.7	47.3	28.6
J 11	42.2	23.8	48.3	24.5	43.0	30.8	44.5	26.4
JL 24	38.4	30.7	45.0	31.7	44.0	30.8	42.5	31.1
Robut 33-1	39.2	26.1	45.2	24.4	43.2	28.8	42.5	26.4
SE	±0.8	±0.7	±0.7	±0.9	±1.0	±1.7		
CV%	3.6	5.8	2.8	6.8	2.3	5.7		

Table 12. Estimates of various components for rust disease score and percentage leaf-area damage in six crosses of groundnut, by Jinks and Jones' (1958) six-parameter model.

Parameter	Rust score	Leaf area damage	Rust score	Leaf area damage	Rust score	Leaf area damage
	Gangapuri × NC Ac 17090		Gangapuri × EC 76446(292)		Gangapuri × PI 259747	
	8.3** ±0.74	83.7** ±7.4	6.7** ±0.7	69.5** ±6.5	4.2** ±0.7	49.1** ±7.2
	2.4** ±0.05	29.4** ±0.3	2.4** ±0.08	24.4** ±1.1	2.9** ±0.03	27.0** ±0.6
	-1.5 ±2.00	-14.8 ±20.0	2.2 ±1.7	23.0 ±16.6	9.4** ±1.8	68.8** ±19.8
	-1.7** ±0.74	-23.1** ±7.5	-0.14 ±0.6	3.9 ±6.4	1.8** ±0.7	13.7 ±7.2
	0.32 ±0.60	8.7 ±5.9	-0.6 ±0.5	-10.3** ±5.0	-3.0** ±0.5	-15.9** ±6.0
	2.1 ±1.28	18.7 ±13.1	0.10 ±1.0	2.5 ±10.3	-4.9** ±1.2	-13.0** ±13.0
	J 11 × NC Ac 17090		J 11 × EC 76446(292)		J 11 × PI 259747	
m	7.4** ±0.5	71.0** ±4.4	8.3** ±0.7	77.8** ±8.6	6.9** ±0.6	69.8** ±6.6
	3.1** ±0.07	27.9** ±0.8	2.7** ±0.09	32.9** ±0.74	2.4** ±0.07	24.7** ±1.1
	1.4 ±1.4	24.4 ±12.9	0.20 ±2.0	7.2 ±24.5	3.3** ±1.7	28.2 ±18.0
	-1.5** ±0.5	8.9** ±4.3	-2.0** ±0.7	-20.7** ±8.6	-0.3 ±0.6	4.0 ±6.5
	-1.7** ±0.4	-15.5** ±4.2	2.3** ±0.7	-28.0 ±7.8	-1.4** ±0.5	13.2** ±5.8
	-0.8 ±0.9	8.6 ±10.4	0.5 ±1.42	4.9 ±15.9	-1.7 ±1.1	8.7 ±11.7

generations from three resistant × two susceptible crosses made at ICRISAT, by generation mean analysis, based on the Jinks and Jones (1958) six-parameter model, showed that resistance to rust was predominantly controlled by additive, additive × additive, and additive × dominance gene effects (Table 12). Duplicate epistatis was observed both for rust-disease scores and leaf-area damage. Further studies are required to show conclusively whether rust resistance is governed by two or three major genes or by many genes. Rust resistance in some diploid wild *Arachis* species appears to be partially dominant in nature (Singh et al. 1984), contrary to the observations made in the crosses involving the cultivated groundnut where resistance is recessive. The dominant nature of resistance in the wild species would simplify a backcrossing program.

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